Antiferromagnetic Spin Reorientation

NiO Interface Spins Shift in Response to Adjacent Co Layer

One of the vexing mysteries facing researchers in magnetic materials is the origin of the exchange-bias effect in which an antiferromagnetic layer pins the magnetization of an adjacent ferromagnetic layer so that it doesn't reverse in an external magnetic field. Building on earlier work with the photoemission electron microscope (PEEM) on Beamline 7.3.1.1 at the Advanced Light Source, a German-American collaboration has taken an important step toward unveiling the secret of exchange bias by observing that spins near a nickel oxide antiferromagnet's surface reorient after deposition of a cobalt ferromagnetic layer. This discovery rules out models of exchange bias based on the common assumption that the spin configuration at the surface of the antiferromagnet is the same as that in its interior (bulk).

Exchange bias is more than a curious phenomenon. It plays a key role in magnetic-device technology, such as the giant-magnetoresistance-effect (GMR) read heads in high-density magnetic data-storage systems (hard disks) already on the market and magnetic random access memory chips under development for low-power, nonvolatile computer memory. But exactly how exchange bias works is not understood. The spin orientation on each side of the antiferromagnet/ferromagnet interface is one of the missing pieces of information. In the previous experiments, investigators achieved a major advance by demonstrating that the alignment of the ferromagnetic spins in a cobalt overlayer is in fact correlated with the spin orientation in a $LaFeO_3$ antiferromagnetic layer. However, owing to the complex crystallography of the $LaFeO_3$, they could not verify a full three-dimensional correlation between ferromagnetic and antiferromagnetic spins.

In the new work, the collaborators used nickel oxide single crystals oriented to have a (100) surface. Nickel oxide single crystals have been well characterized in the literature and exhibit large antiferromagnetic domains that the PEEM with a spatial resolution of 50 nm for magnetic structures can easily image using the technique of x-ray magnetic linear dichroism (XMLD). Image contrast arises because the relative orientation of the polarization of the x-ray beam and the magnetic axis in the antiferromagnetic domains (changeable by rotating the crystal) determines the absorption. To image the cobalt ferromagnetic layer, the group used the now traditional x-ray magnetic circular dichroism (XMCD) with circularly polarized light.

The first set of XMLD measurements, made on bare nickel oxide, revealed a complex domain pattern related to that previously known for bulk single crystals, but with some differences. In the bulk, the domains are defined by the (111) crystallographic planes in which the spins lie and the [211] directions in which they are aligned. Analysis of the PEEM images yielded the same [211] magnetic axes but in a different arrangement. In addition, the PEEM data showed that some of the boundaries between the domains (domain walls) had decreased magnetic symmetry. Noting that the PEEM is sensitive to material only a few nanometers below the surface, the investigators concluded that the surface domain structure deviated from that of the bulk.

When a ferromagnetic cobalt layer eight monolayers thick was deposited on the nickel oxide, the story changed dramatically. The spins in the nickel oxide reoriented themselves in such a way that only domains with walls in (100) crystallographic planes remained. Moreover, the spins in the domains assumed [110] directions parallel to the interface. XMCD measurements showed that the magnetization in the cobalt domains was aligned, domain by domain, parallel to the magnetic axes of the nickel oxide domains. Heating the sample to above the antiferromagnetic transition (Néel) temperature destroyed this correlation. This graphic demonstration of spin reorientation near the nickel oxide surface means that the exchange bias mechanism is not based on the bulk spin structure of the antiferromagnet. ■

Hendrik Ohldag (510-486-6645), Advanced Light Source Division, Ernest Orlando Lawrence Berkeley National Laboratory; Stanford Synchrotron Radiation Laboratory; and Universität Düsseldorf.

H. Ohldag,, A. Scholl, F. Nolting, S. Anders, F. U. Hillebrecht, and J. Stöhr, "Spin reorientation at the antiferromagnetic NiO(001) surface in response to an adjacent ferromagnet," *Phys. Rev. Lett.* **86**, 2878 (2001).

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- **Exchange bias mechanism in magnetic nanolayers unexplained**
  - *Effect discovered almost 50 years ago*
  - *Antiferromagnet pins magnetization direction of adjacent ferromagnet*
  - *Key phenomenon in advanced magnetic devices (GMR read heads, MRAMs, …)*
- **Mechanism depends on the spin orientation at the interface**
  - *Several proposed models*
  - *Antiferromagnetic spin structure usually assumed to be that in bulk*
  - *Experimental tools to image antiferromagnet structure near surfaces lacking until recently*
  - *Microscopic understanding still not in hand*
- **Photoemission electron microscopy of NiO crystal with Co layer**
  - *Domain structure near surface of bare NiO imaged by x-ray magnetic linear dichroism*
  - *Observed spin reorientation near NiO interface after deposition of Co layer*
  - *Co domains aligned with the magnetic axes of the NiO interface domains*
  - *Finding rules out models based on bulk antiferromagnet spin configuration*

H. Ohldag (ALS, Stanford Synchrotron Radiation Laboratory, and Universität Düsseldorf); A. Scholl and S. Anders (ALS); F. Nolting (ALS and Stanford Synchrotron Radiation Laboratory); F.U. Hillebrecht (Max Planck Institute for Microstructure Physics, Halle); and J. Stöhr (Stanford Synchrotron Radiation Laboratory). **[*Phys. Rev. Lett.* 86, 2878 (2001)]**

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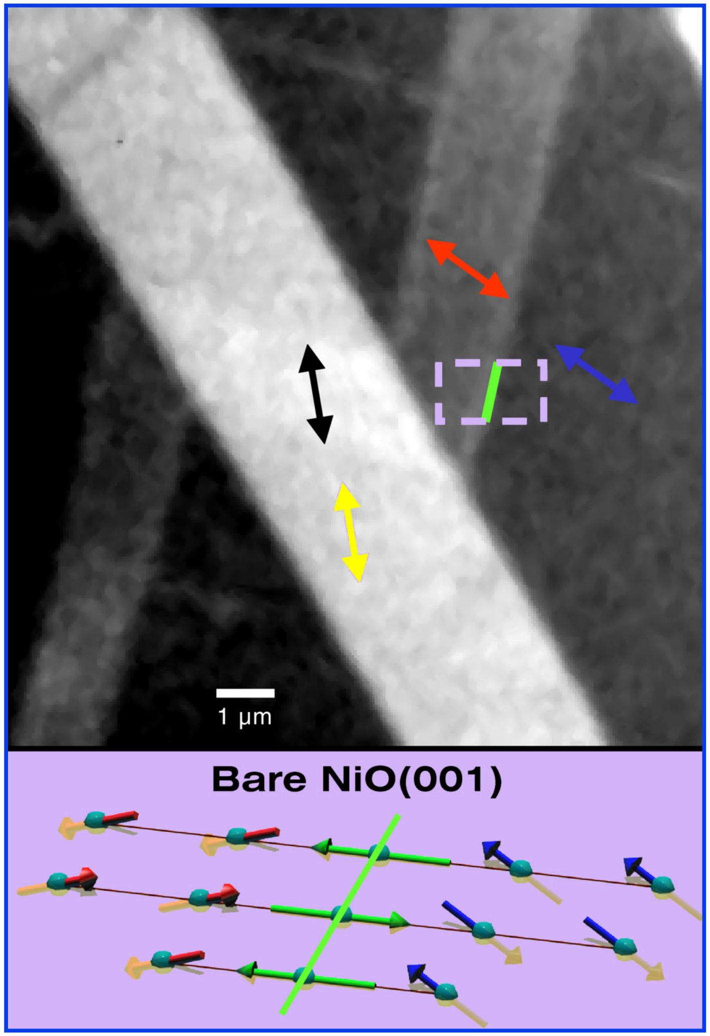

Antiferromagnetic Domains on NiO(001)

– *The colored arrows indicate the projections of the anti-ferromagnetic axes in the surface plane for four types of domains*

– *Domains with identical in-plane projections can be distinguished by examining their orientation out of the surface plane (see sketch at bottom for the area in the dashed box)*

– *The green line represents a domain wall where the spins are in-plane*

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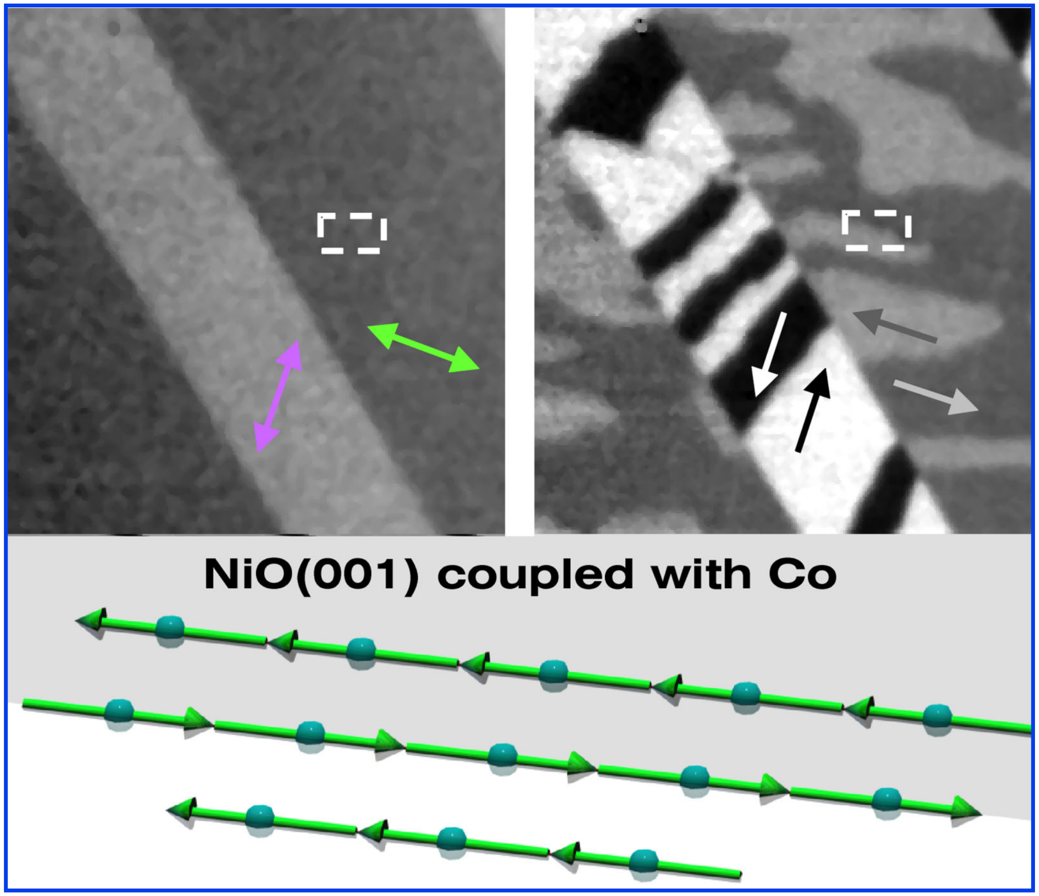
Antiferromagnetic domains after deposition of eight monolayers of cobalt. The anti-ferromagnetic axes have rotated into the surface plane so that only two types of domains can be distinguished.



On top of each antiferromagnetic domain, two ferromagnetic domains form with their magnetiza-tion in either of two directions parallel to the antiferro-magnetic axis underneath.

The rotated NiO spins for the area in the dashed box, which is overlaid by two cobalt domains (light and dark areas).

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